

# Energy Informatics: Overview (II)

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# Learning Objectives

From this lecture, it is aimed that the students will be able to learn about

- **Learn the basic concepts in smart grid**
- **Learn about the communications and networking technologies for smart grid**
- **Understand the challenges, advantages and disadvantages of applying different ICT (Information and Communications Technology) technologies for smart grid**

# Invited Talk by World-leading Scientist Today

## Speaker:

Øystein Ulleberg

*Principal Scientist/Forskningsleder,  
Institute for Energy Technology (IFE);  
Associate Professor, ITS, University of Oslo*



**Title:** Renewable Energy Systems

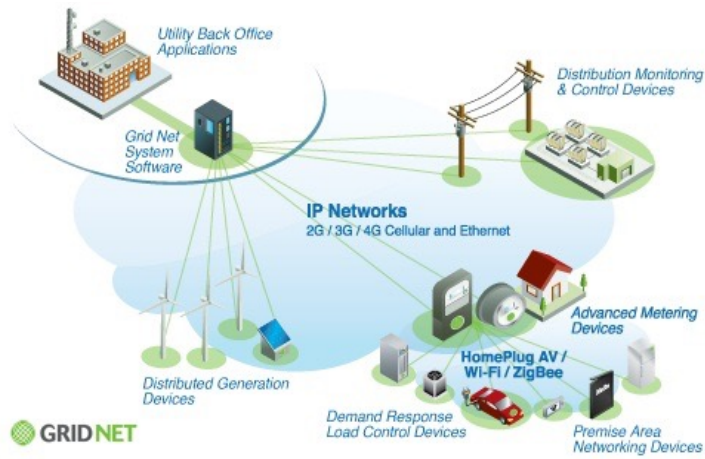
**IFE (Institute of Energy):** IFE was founded in 1948, and is a frontrunner leading internationally in energy research.



# Outline

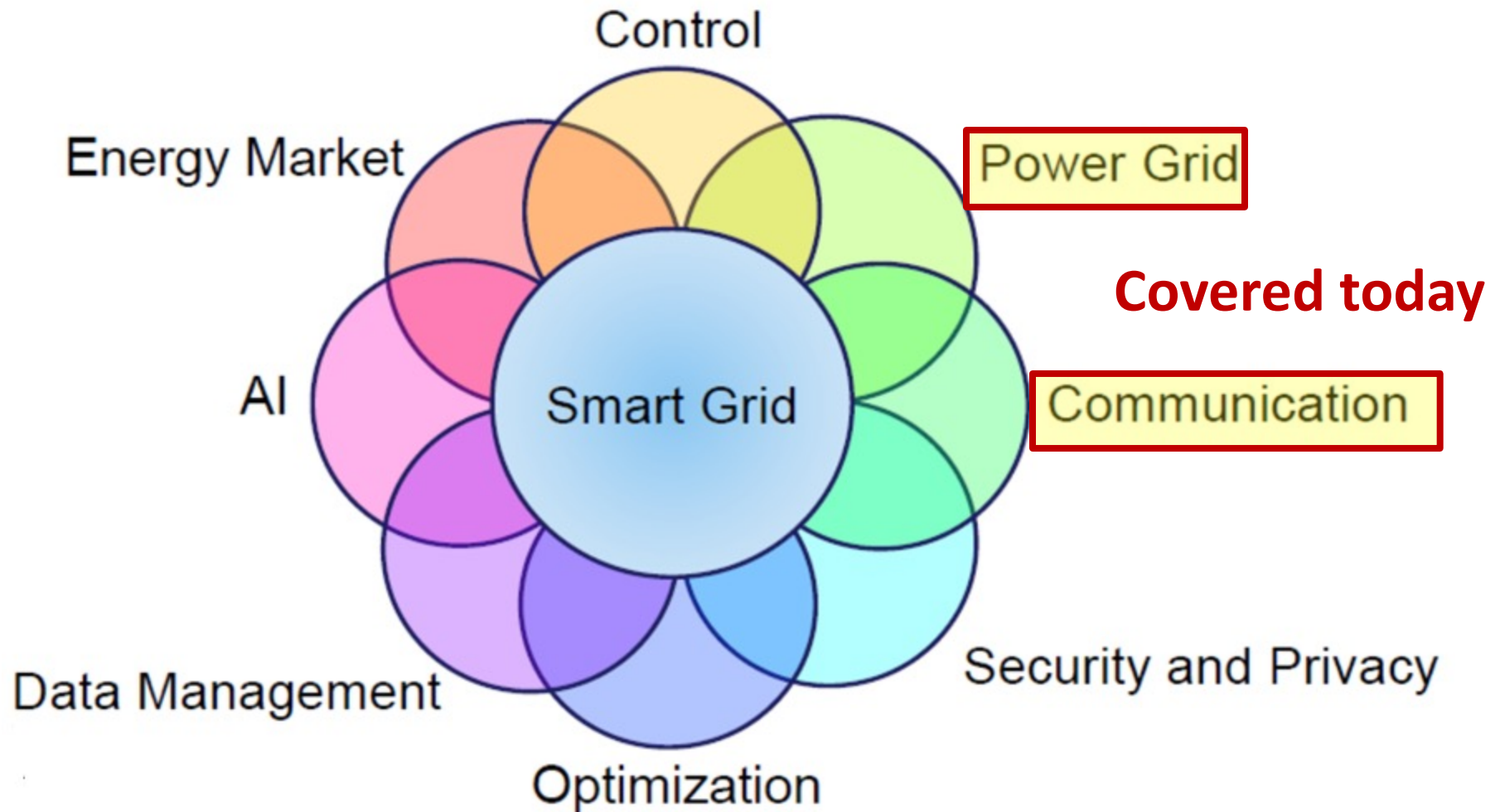


## Smart Grid



## ICT for Smart Grid

# Smart grid: an interdisciplinary field



# Power systems



**Power generation (hydropower, solar, wind power, nuclear etc)**



**High-voltage power transmission**



**Medium voltage distribution lines**



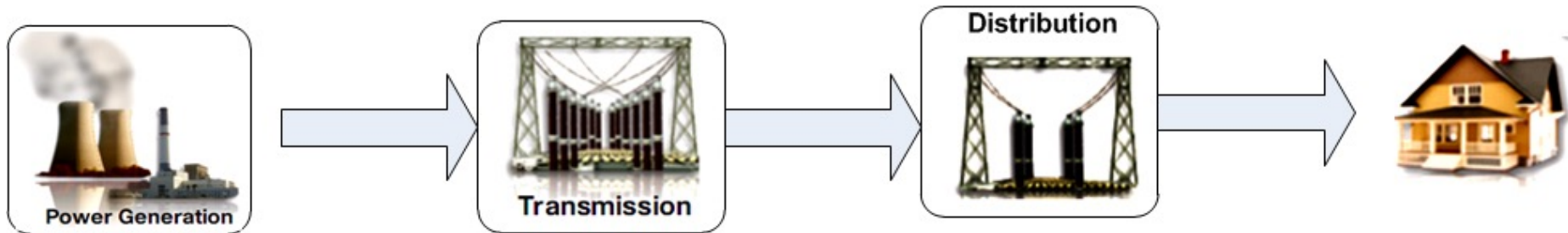
**Commercial, industrial and residential users**

# Traditional Power Grid

Power is generated in a plant

Power is distributed through the long-distance high-voltage transmission networks to the local community

Power is distributed to the customers



**One-way Flow** of Electricity and Information



# Problems with Current Power Grid

Not efficient

**Transmission loss = 20%**

Not reliable

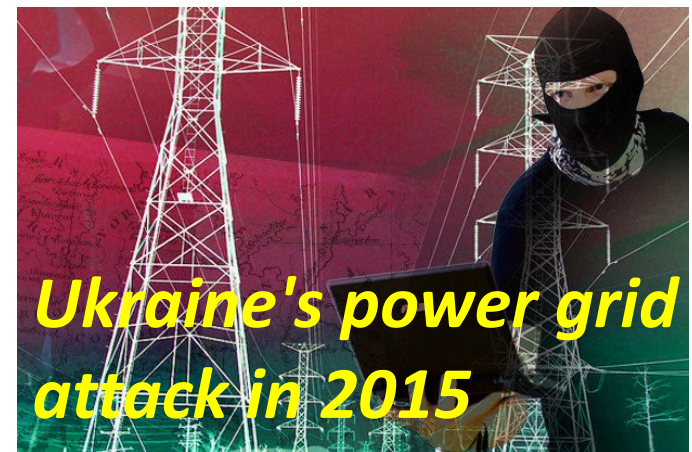
- Failure can quickly spread

Not secure

- Cyber attack

Not green

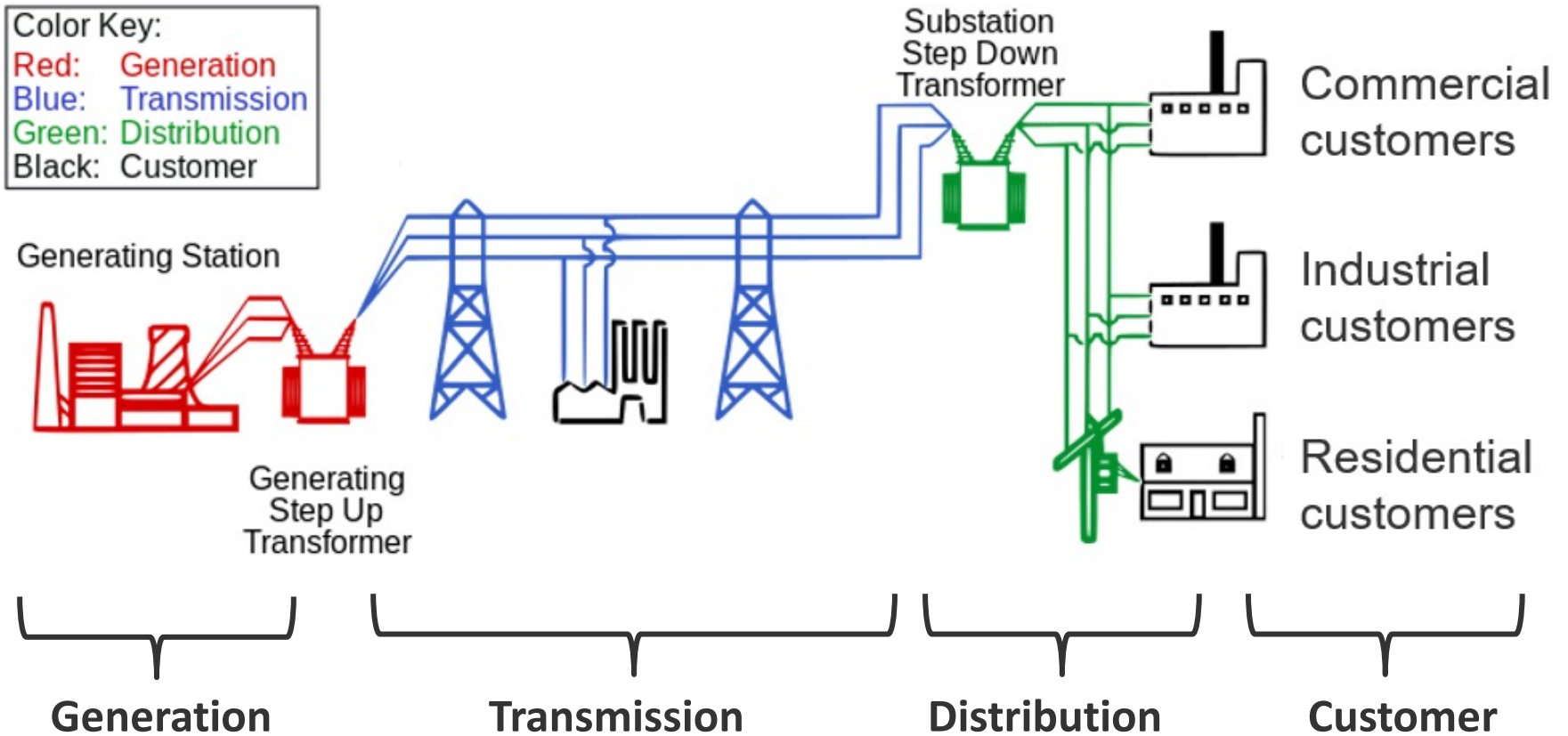
- Electricity accounts for 41% of energy related CO<sub>2</sub> emissions



**The Grid Should be Smarter**



# Power systems – abstract model



# Power generation sources



**Power plants**



**Renewable energy sources**

- Wind farm, Solar power



**Hydropower**

**99% of all power production in Norway comes from hydropower**

**Q: which source produces most power in Norway?**

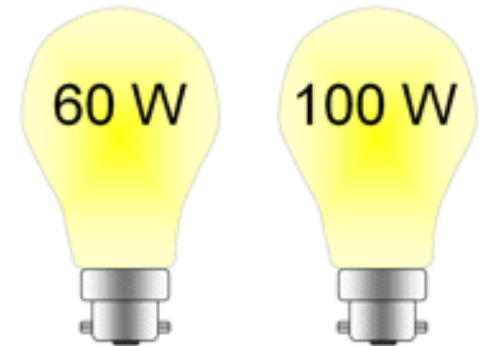
# Concept: Power

**Power: Instantaneous rate of energy consumption; How hard you work!**

**Power = Voltage x Current**

**Power Units:**

- Watts = amps times volts (W)**
- kW =  $1 \times 10^3$  Watt**
- MW =  $1 \times 10^6$  Watt**
- GW =  $1 \times 10^9$  Watt**
- TW =  $1 \times 10^{12}$  Watt**



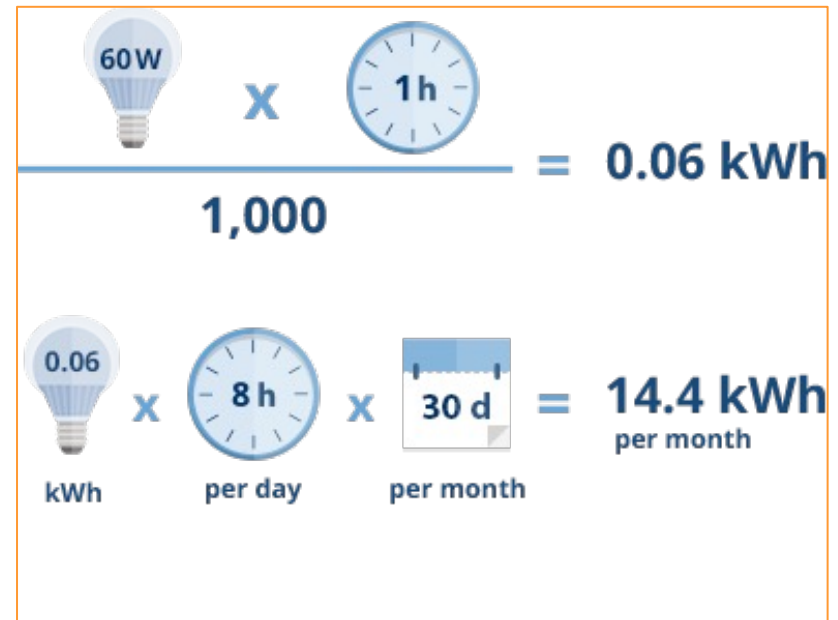
# Concept: Energy

**Energy Consumption = Power \* Time:**

- Energy is what people really want from a power system,
- How much work you accomplish over time.

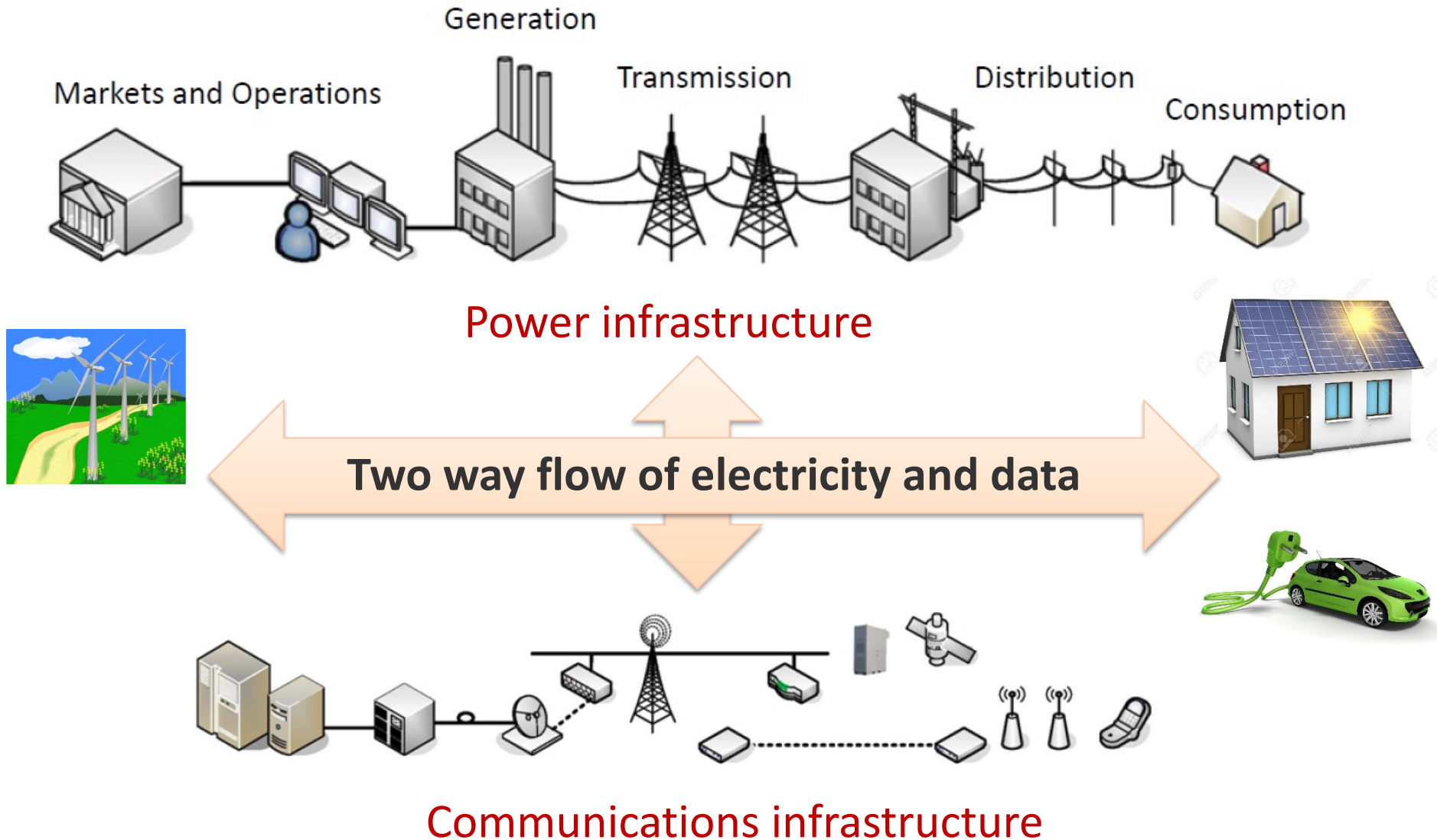
**Energy Units:**

- Joule= 1 watt-second (J)
- kWh=kilowatt-hour = 1000watt \* 3600sec =  $3.6 \times 10^6$  J



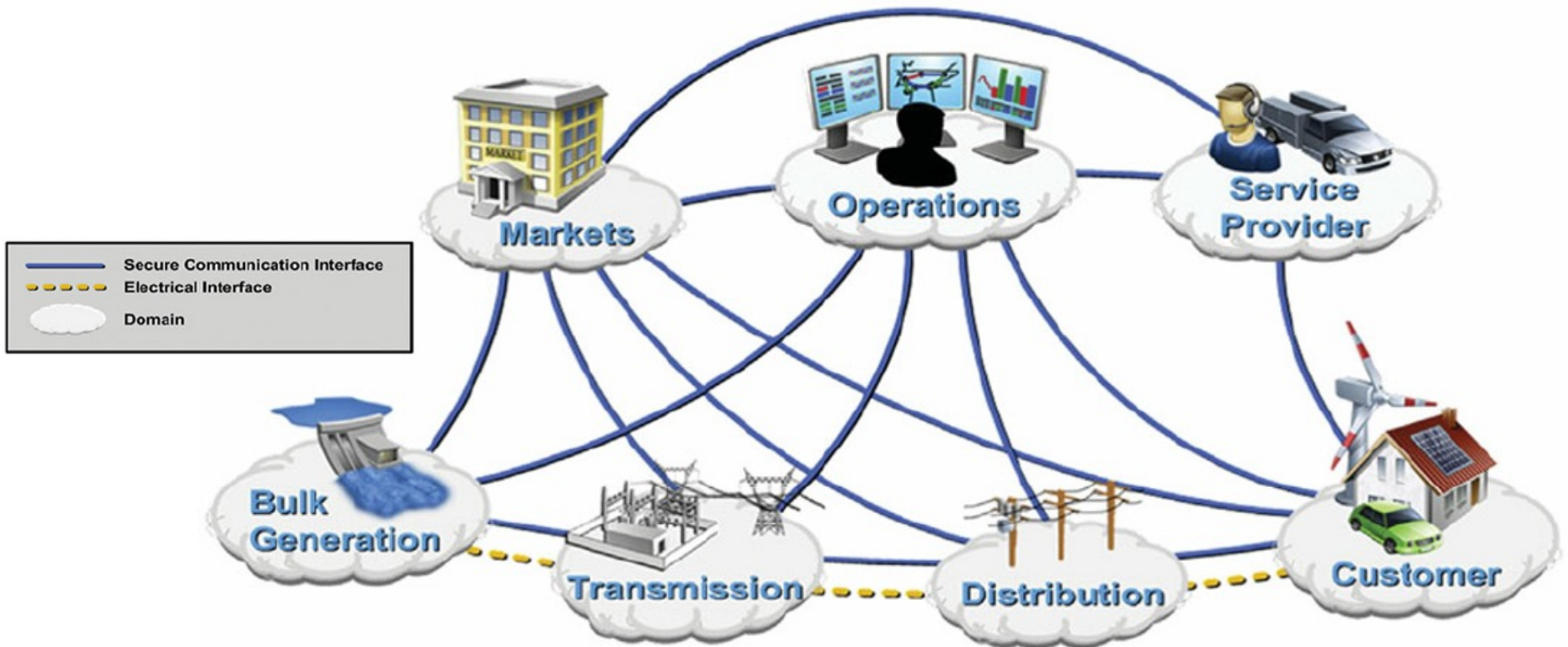
**Annual electric energy consumption in Norway in 2021 is about 223 TWh**

# Smart Grid = Power Grid + ICT



\*ICT: Information & Communications Technology

# NIST (National Institute of Standard and Technology, USA) Conceptual Model for Smart Grid



Interaction between 7 Smart Grid units through information flow and energy flow



# NIST Conceptual Model for Smart Grid

## Customers:

The end users of electricity

Typically, three types of customers: residential, commercial, and industrial

Customers may also generate, store, and manage the use of energy.

— **Q: How?**

## Market

The operators and participants in electricity markets

Participants in wholesale market: day ahead, hour ahead (We will discuss more in the lecture “Energy Market and Game Theory”)

A market may involve prediction, bidding, auctions

# NIST Conceptual Model for Smart Grid

## **Service Providers:**

Organizations that provide service to both utilities and electricity consumers

Internet service providers, charging stations operators,...

## **Operation**

The manager of the flow of electricity

Independent System Operators (ISOs) or Regional Transmission (System) Operations (RTOs). An ISO or RTO serves as a third-party independent operator of the transmission system.

## **Bulk Generation**

Major power plants. The generators of electricity in bulk quantities. May also store energy for later distribution.

# NIST Conceptual Model for Smart Grid

## Transmission

- Carriers of bulk electricity over long distance
- A system operator is responsible for the security of power supply in its area
- In the Nordic countries, the system operators have the responsibility for both the security of supply and the high-voltage grid (the transmission grid).
- Statnett is Norway's transmission system operator

**Statnett**

## Distribution

- Distribution of electricity to and from customers
- May also store and generate electricity

**Hafslund** 

 **BKK**

# Smart Grid Concept and Vision

- **Cost-effective:** cost-effective production and delivery of power
- **Green:** greater use of renewable resources; support for a large number of electric vehicles
- **Customer-oriented:** consumers can choose energy usage
- **Secure:** resilient to various cyber attacks
- **Dynamic:** dynamic pricing and load control
- **Reliable:** higher reliability of services
- **Communication and control infrastructure to augment power grid operations**

**The transformation to a smart grid requires integrating computation, networking, communications and control**

# **ICT FOR SMART GRID**

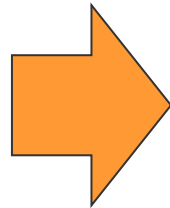
# Smart Grid needs communications and networking technologies

- **Smart metering and Advanced Metering Infrastructure(AMI)**
- **Distributed generation and renewable energy integration**
- **Power outage detection**
- **Real-time monitoring, diagnostics and protection**
- **Big data generated by massive number of sensors, meters, and telemetry**
- **Further analysis control, real time pricing**
- **Communications network support intelligent energy scheduling**



# Old electricity meters → Smart Meters

Analogue, Manual,  
annually or monthly

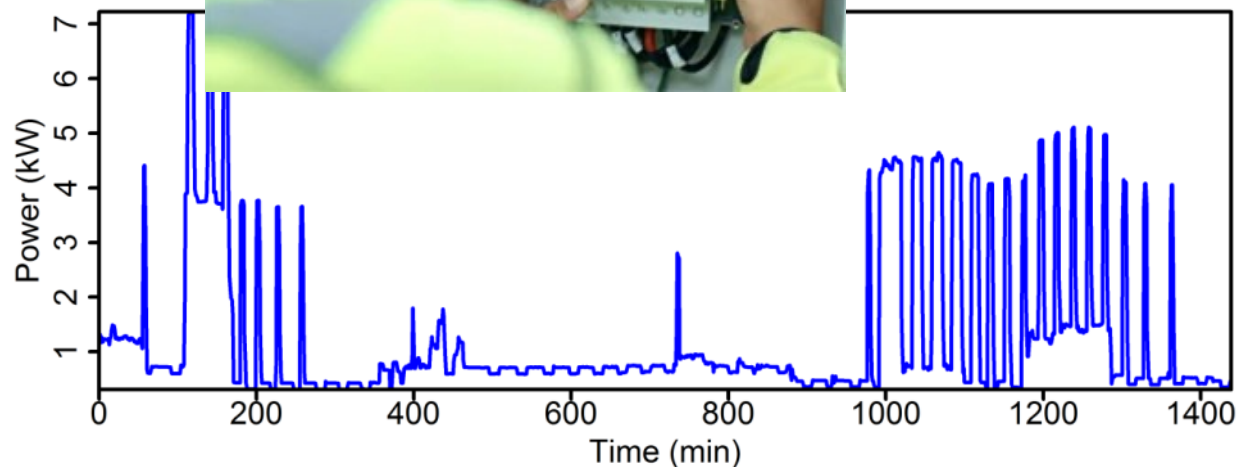


Digital, Bidirectional  
communication



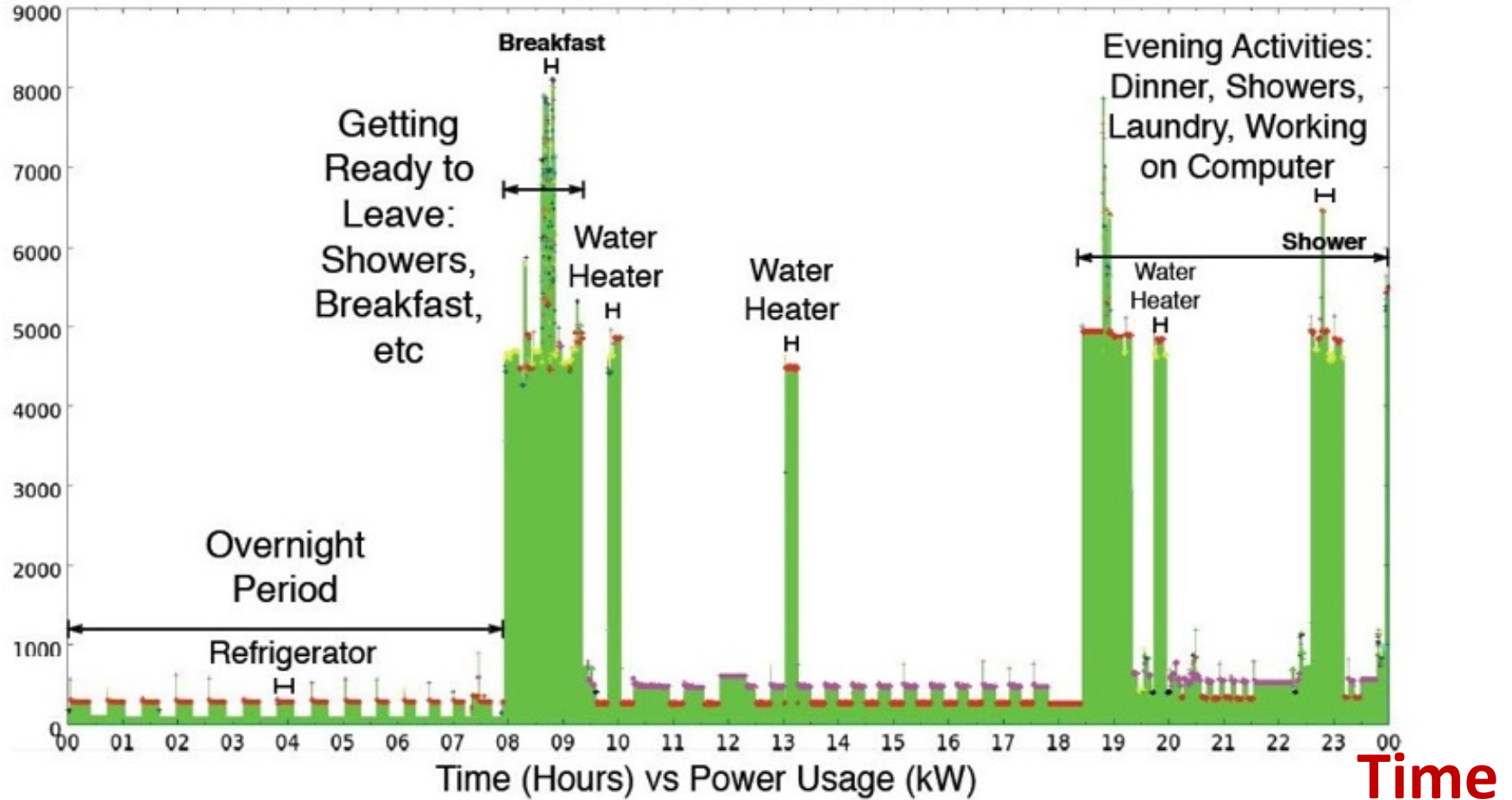
Hafslund Nett

**Q:** Any consequence of energy consumption data being available through smart meters?



# Smart Meter Privacy Issues

## Power Usage



# Smart Meter Functions

Smart meters perform the following functions

**Energy consumption measurement**

**Communications with other intelligent devices in the home and utility**

**Time-based pricing**

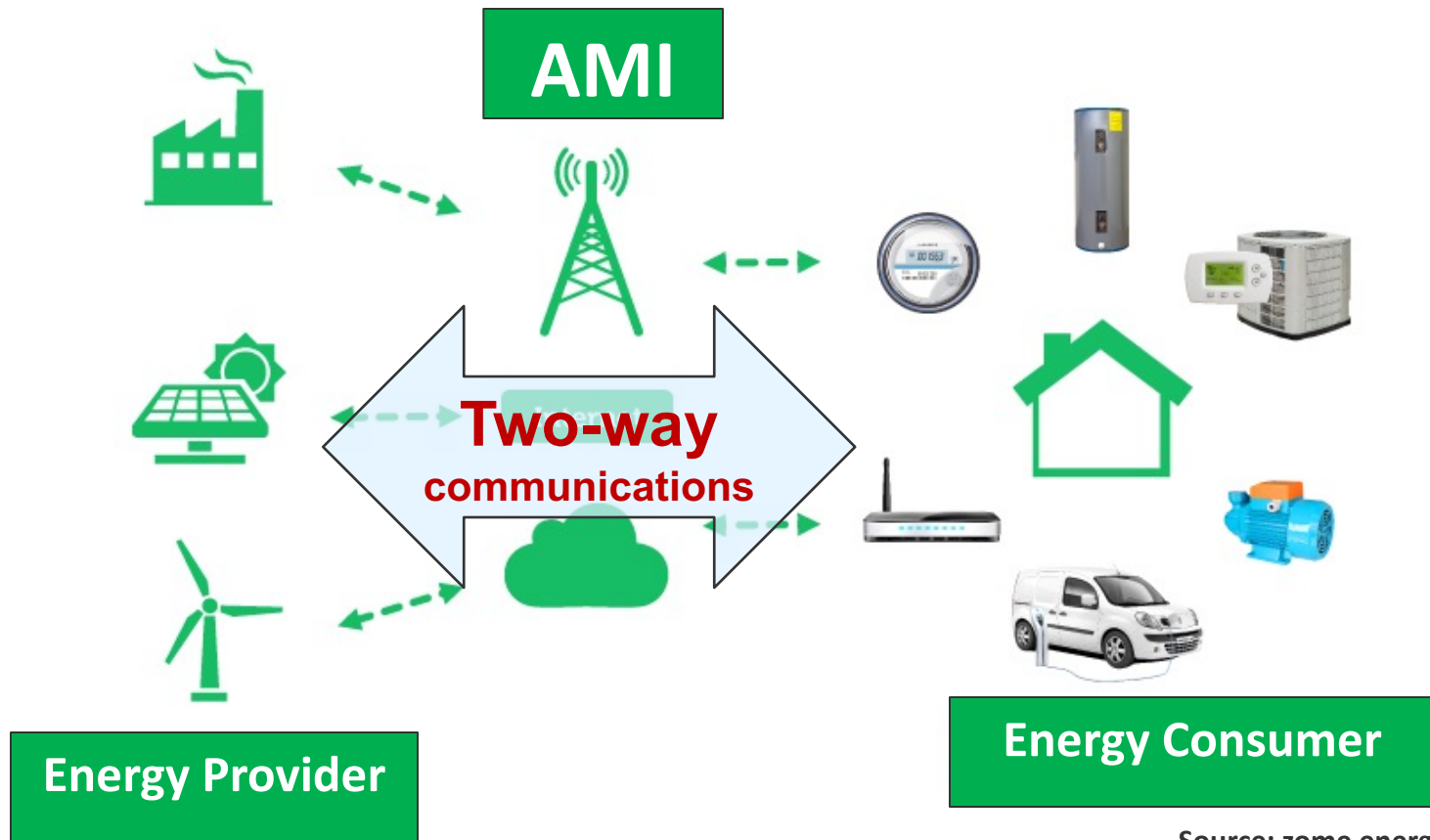
**Loss of power notification**

**Remote turn on / turn off operations**

**Power quality monitoring**

**NVE is the Norwegian energy market regulator, and has decided that all customers in Norway shall receive new smart meters by 1 January 2019. About 2.5 million meters shall be replaced in Norway.**

# Advanced Metering Infrastructure (AMI)



Source: zome energy networks

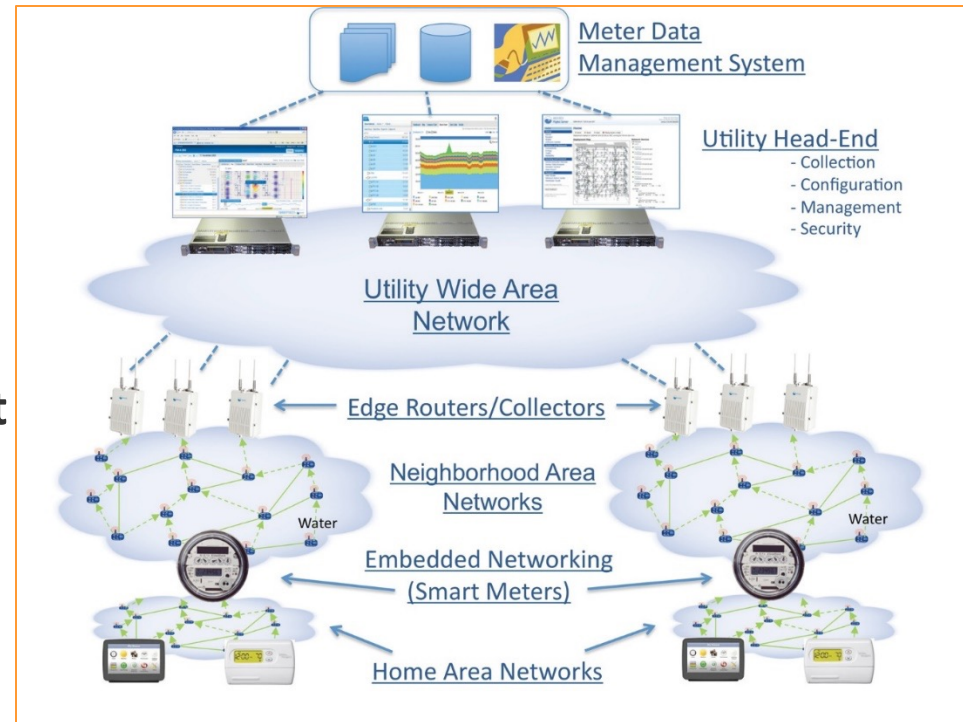
Smart meters are not working separately. They are organized as networks.

AMI is an integrated system of smart meters, communications networks, and data management systems that enables two-way communication between energy providers and energy customers.

# Advanced Metering Infrastructure (AMI)

AMI integrates a number of technologies:

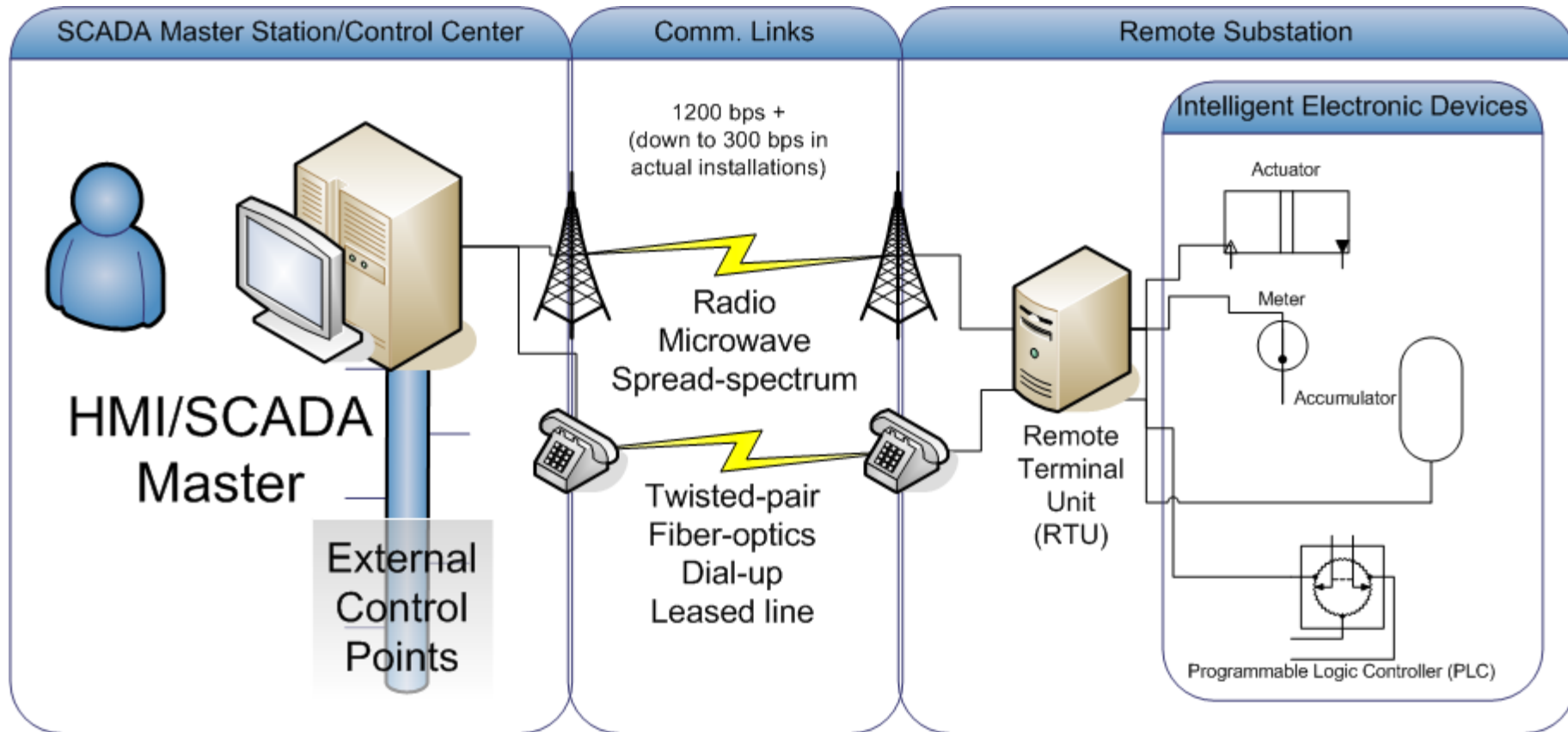
- Smart meters at the consumer end
- Communication networks at different levels of the infrastructure hierarchy to connect the two ends
- Meter Data Management Systems (MDMS)
- Platform integrating the collected data into application at utility provider



Source: National Energy Technology Laboratory for the U.S. Department of Energy

# Supervisory control and data acquisition (SCADA)

**SCADA** is solution for data acquisition, monitoring and control over large geographical areas. The data is transferred to a master station to implement the necessary processing and control algorithms.



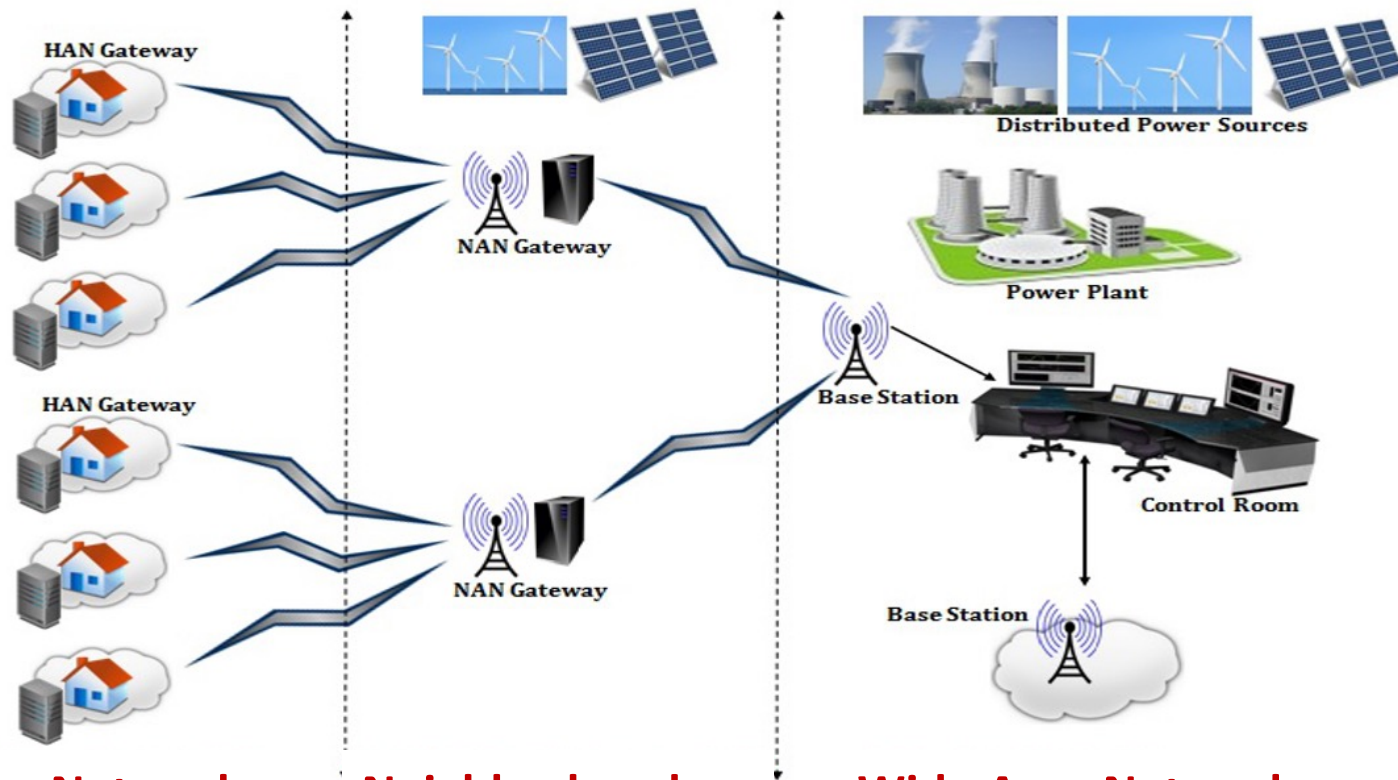


# Supervisory control and data acquisition (SCADA)

SCADA systems consist of:

- **RTU (Remote Terminal Unit):** conveys signals from sensors to the control center.
- **Communication networks:** transfer data between field data interface devices and control units and the computers in the SCADA central host.
- **MTU (Master Terminal Unit):** a central computer server displays the entire system being monitored and controlled

# Communications Networks



## Home Area Networks

HAN: interconnects appliances, energy management units, and home displays.

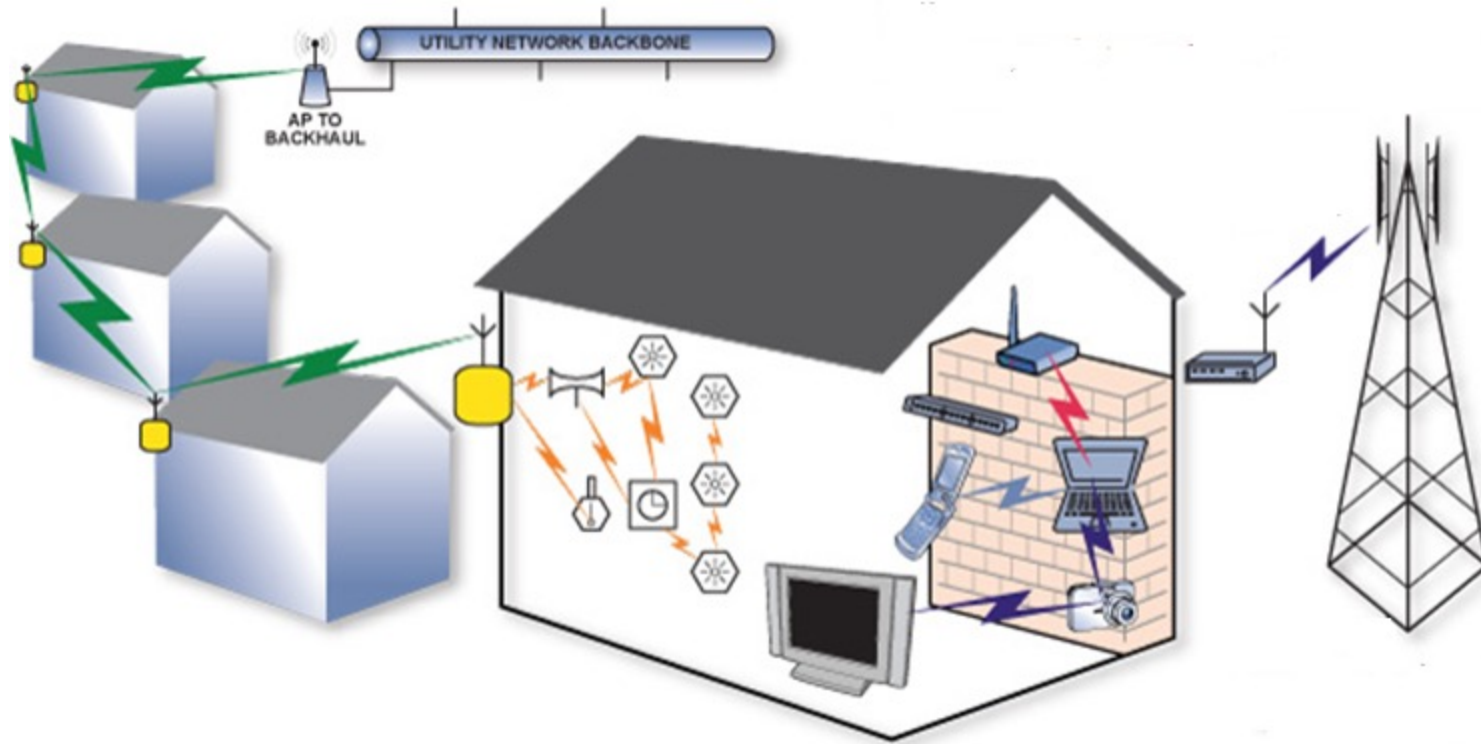
## Neighborhood Area Networks

NAN: interfacing metering data and connect multiple HANs to local access points

## Wide Area Networks

WAN: between the NANs and the utility systems to transfer information

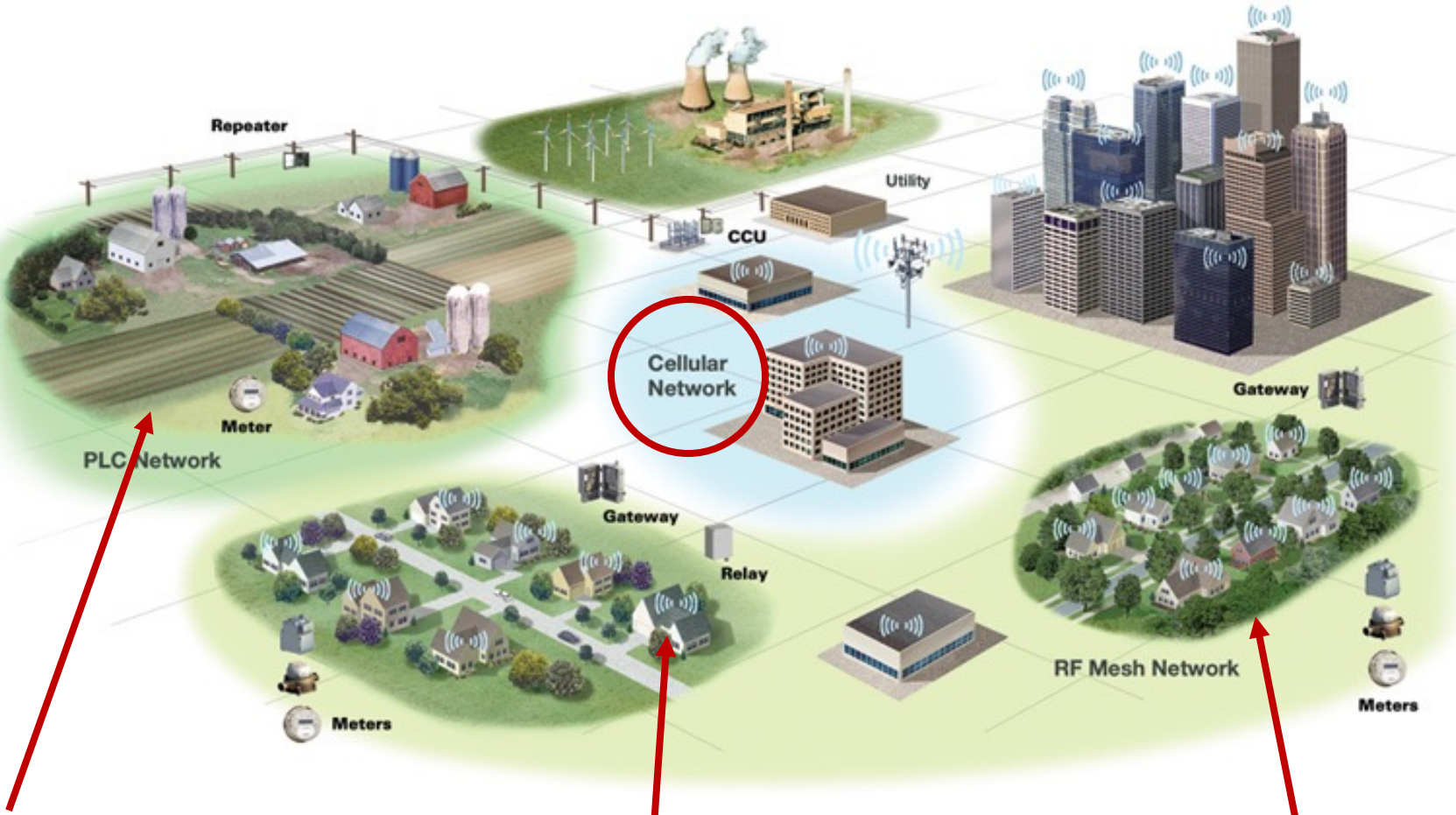
# Home Area Networks (HAN)



**HAN gathers sensor information from a variety of devices within a house, sends control information to these devices to better control energy consumption, and provides access to in-home appliances.**

**HAN can use ZigBee, WiFi, Power Line Communications (PLC)**

# Different communication technologies

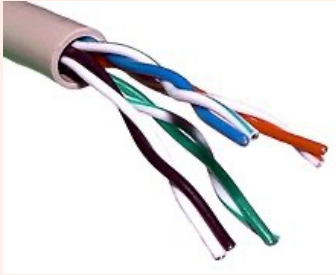


**Powerline Communication (PLC)**

**Wireless Sensor Networks using Zigbee**

**Mesh Networks**

# Communication Technologies for home area networks

| Technology | Data Rates   | Coverage | Medium  | Band Licensed |
|------------|--------------|----------|---|---------------|
| PLC        | 1-200Mbps    | 1500m    | Power cable   | Free          |
| Ethernet   | 100Mbps      | 100m     | UTP (unshielded twisted pair) cable<br> | Free          |
| WiFi       | 5-100Mbps    | 30-100m  | Wireless  | Free          |
| Zigbee     | 0.02-0.2Mbps | 10-75m   | Wireless  | free          |

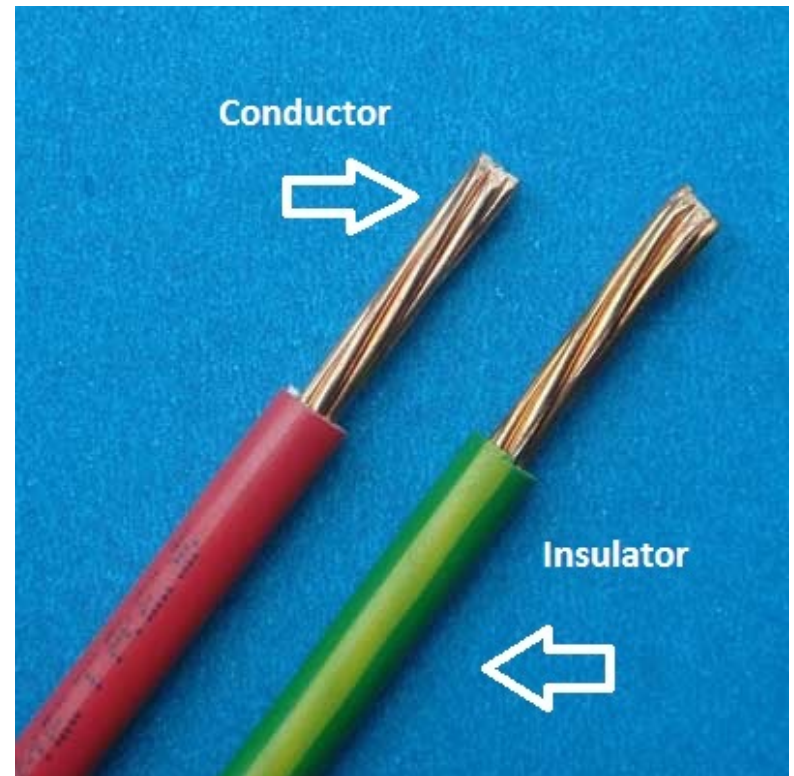


# Power Line Communications (PLC)

PLC is a communication technology that enables sending data over existing power cables.

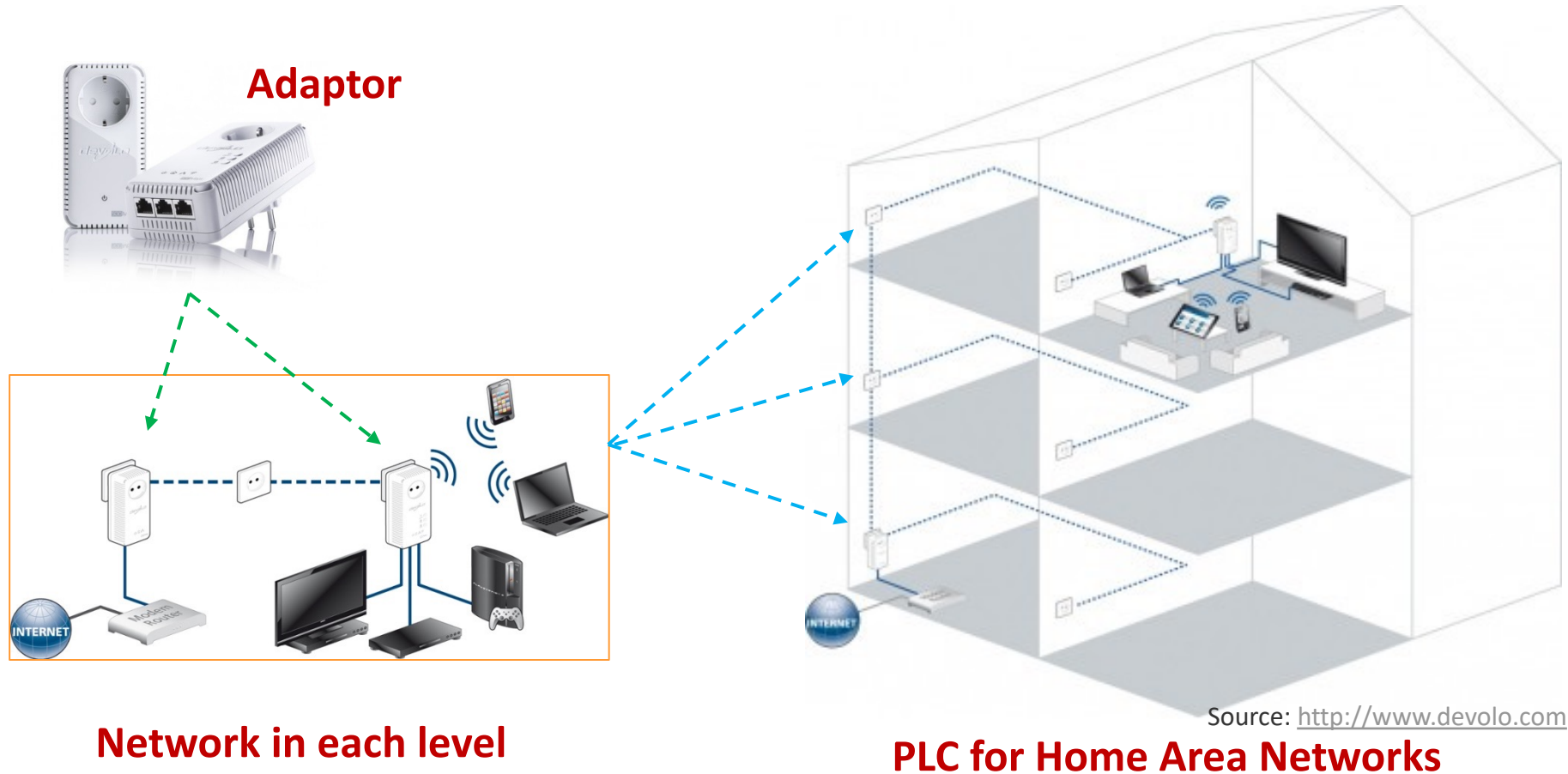
PLC carries data on a conductor that is also used simultaneously for electric power transmission or electric power distribution to consumers.

PLC is a wired communications technology, it can compete with wireless technologies with low cost since the infrastructure already exists



# An example of PLC at home

PLC uses the household power grid to transfer data between computers equipped with suitable adapters. The data is modulated prior to transfer and sent as a signal via household power lines.

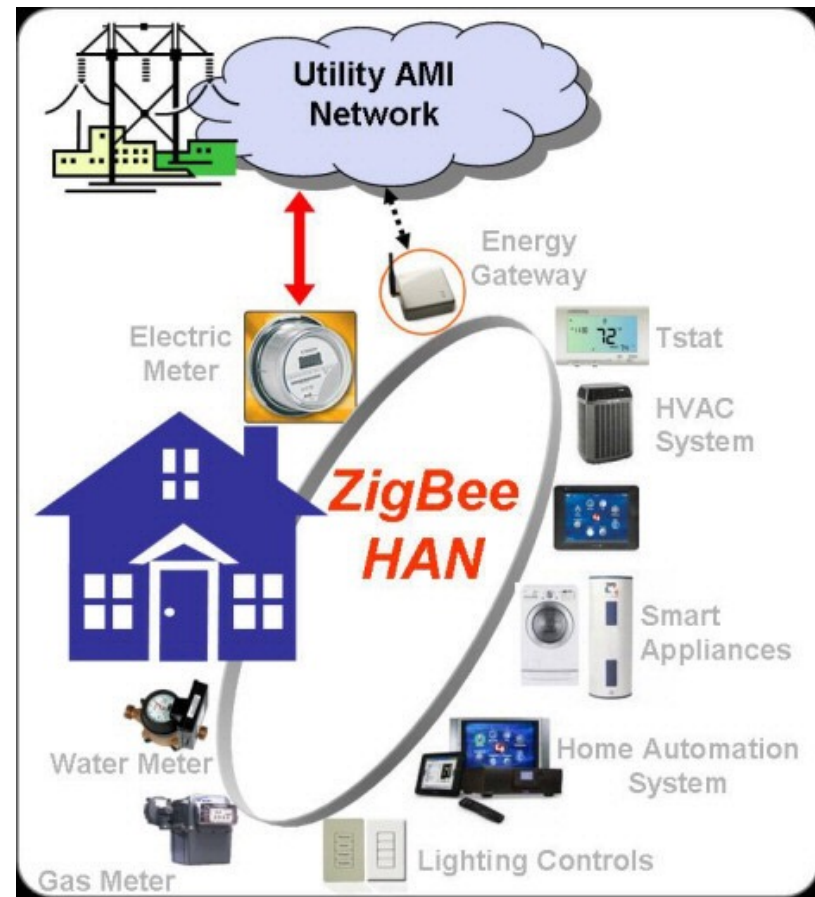


# IEEE 802.15.4 - Zigbee for Smart Energy at Home

Zigbee is a short-range, low-data rate, energy-efficient wireless protocol for WSN

Zigbee defined two smart grid application profiles

- **Home automation:** lighting, window shades, monitoring, security
- **Smart energy:** Zigbee devices can control power supply switch of home appliance; Zigbee enabled smart meters efficiently manage **demand response**; actively respond to different prices and effectively balance the power consumption load in the power grid

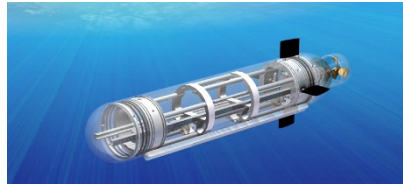




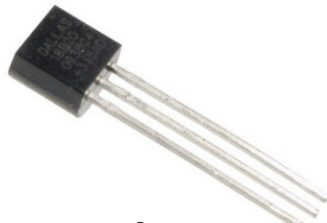
# Sensors



Sound sensor



Underwater sensor



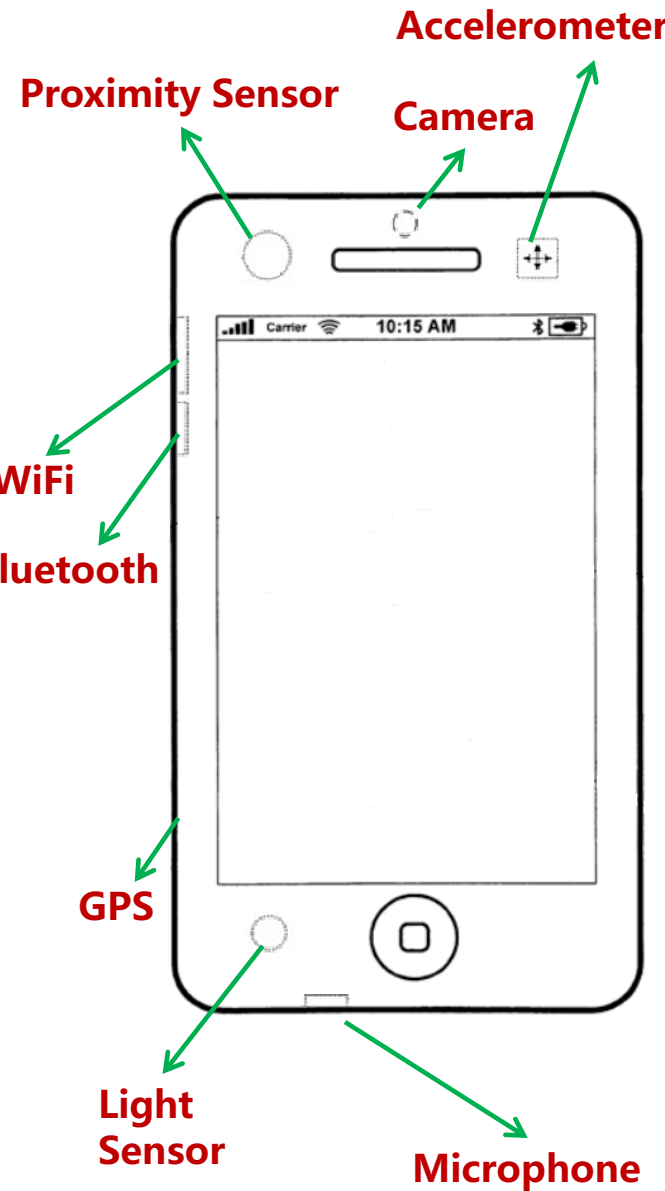
Temperature sensor



Pressure sensor

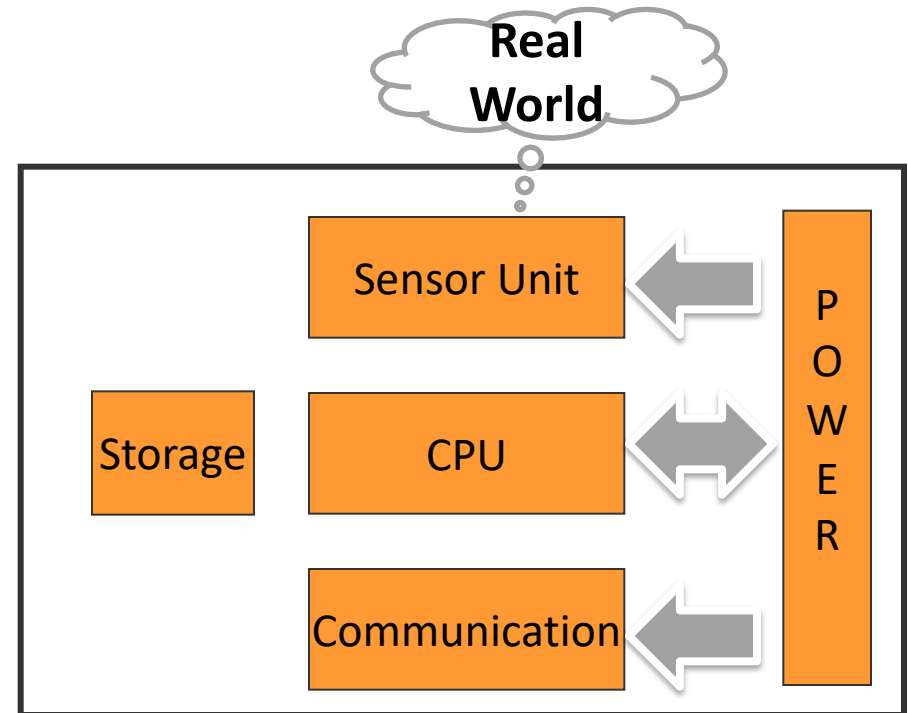


Sensor with solar panel



# Sensor Nodes Model

- **Communication:** low-power; low data rate and limited range.
- **Low-power processor:** Limited processing.
- **Memory:** limited storage
- **Limited power:** powered by battery with long-time operation in unattended areas
- **Sensors**
  - temperature, light, etc.
  - Cameras, microphones.

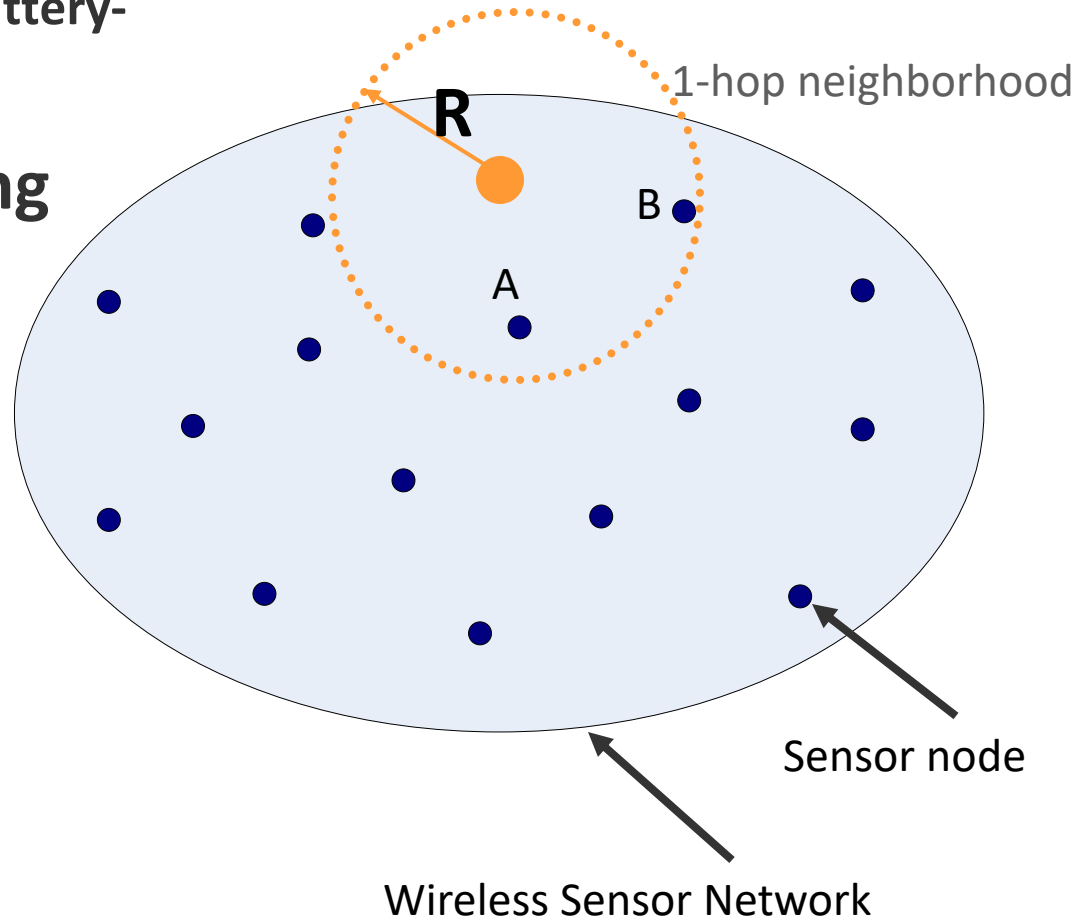


# Wireless Sensor Networks

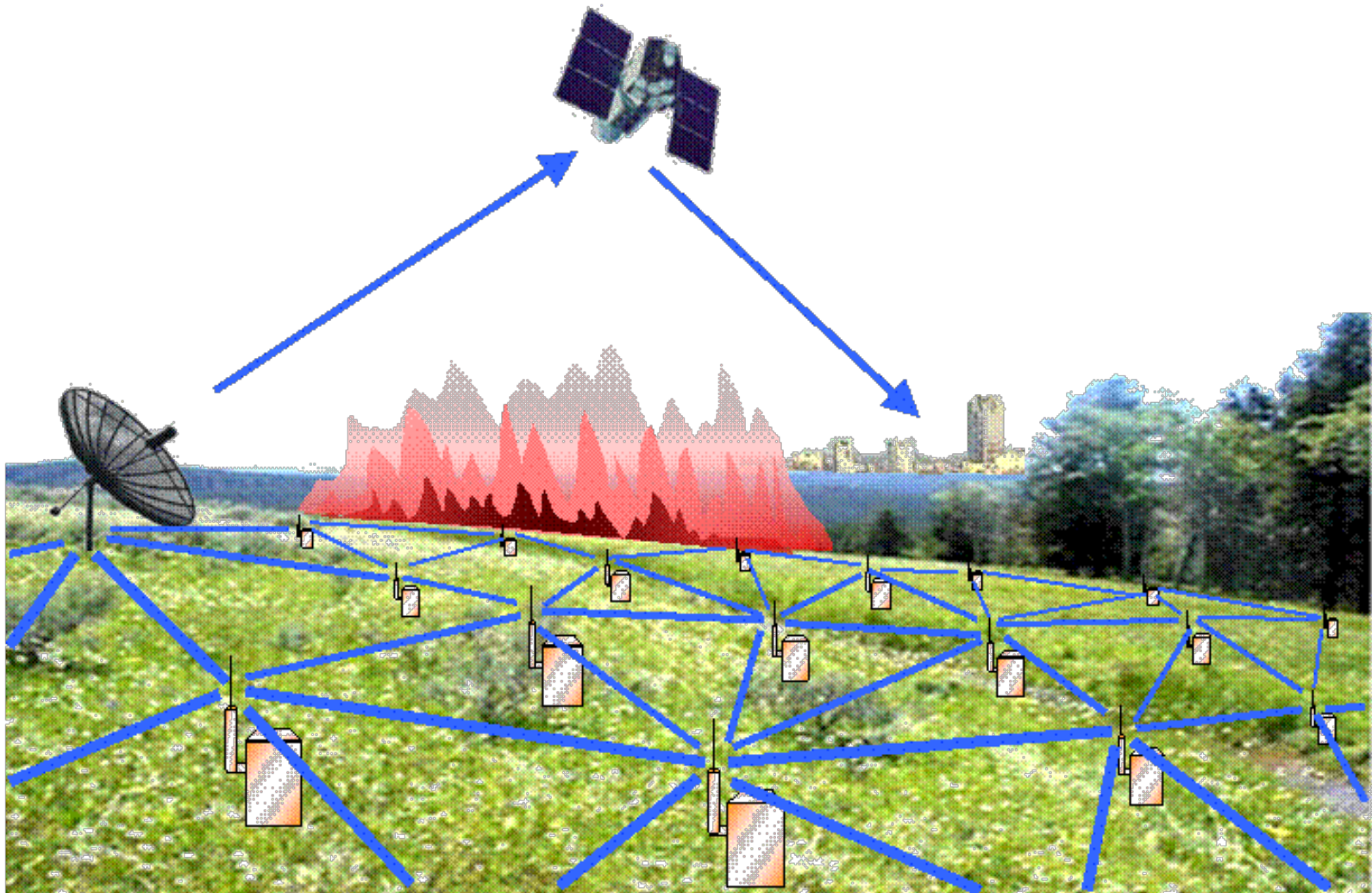
- Networks of typically small, battery-powered, wireless devices.

- On-board processing
- Communication
- Sensing

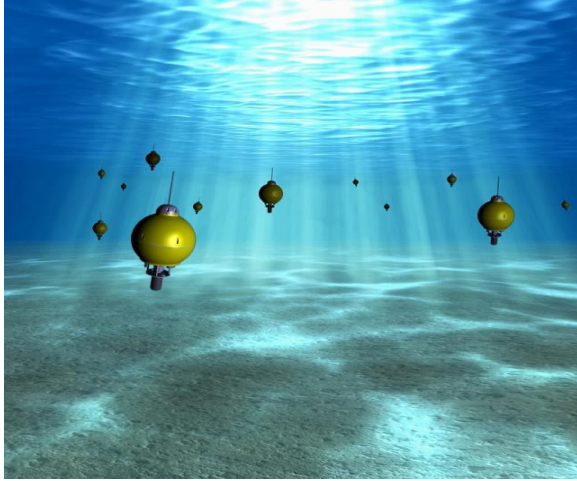
- $R$ : transmission range
- $V$ : the set of sensor nodes



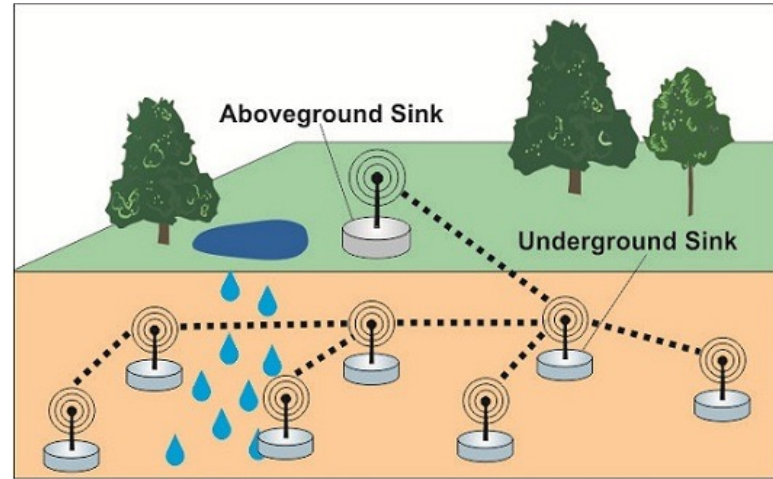
# Typical application and system architecture: forest fire detection



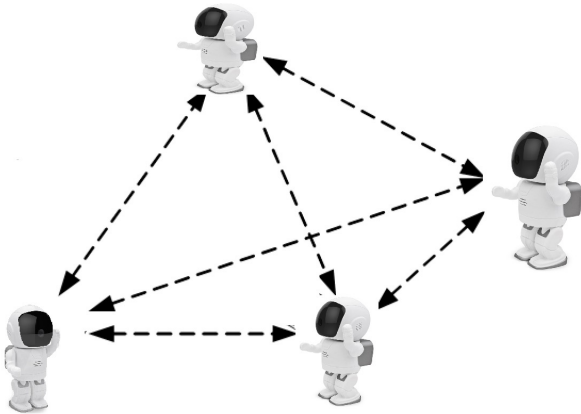
# Different Types of Sensor Networks



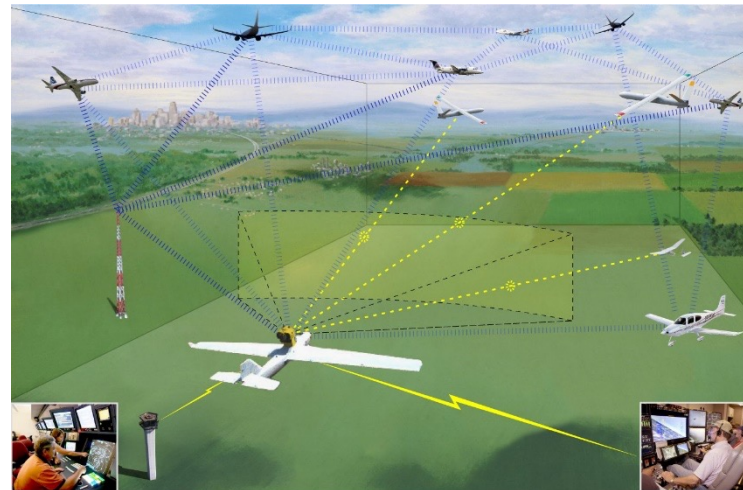
***Underwater*** Sensor Networks



***Underground*** Sensor Networks



***Mobile*** Robot Networks



***UAV (Unmanned Aerial Vehicles)/Drones***



# WSNs for Smart Grid: **power generation side**

WSNs enable communications and control capabilities at low cost. Both utilities and customers can transfer, monitor, predict, and manage energy usage effectively.

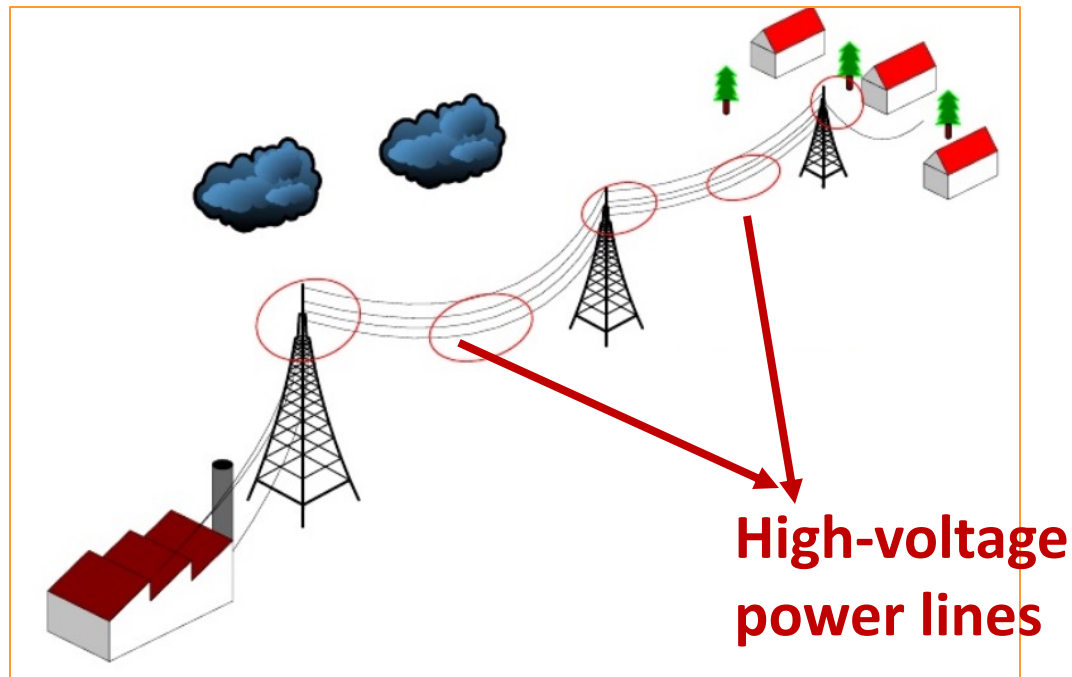
In the traditional power grid, energy generation facilities are generally monitored with wired sensors

- **limited in numbers**
- **located only at a few critical places**

In practice, the renewable energy generation facilities in the smart grid can be in remote areas, and operate in harsh environments

WSNs offer an ideal technology for continuous monitoring and control of the generation facilities in the smart grid

# WSNs for Smart Grid - **Transmission side**



- Real-time monitoring and securing of the transmission lines
- Close monitoring in case of lightning, icing, hurricanes, landslides, overheating
- Detecting and locating failure in power lines; and relaying information to control stations

# WSNs for Smart Grid - **Distribution side**

## Smestad substation



- Real-time monitoring of the distribution segment: substations, power outage
- Substations transform voltage from high to low, or the reverse. Substation failure consequences can be very severe
- Xcel Energy is the first power company to use UAV/drones to inspect substations in 2015



**MORE CONSIDERATIONS...**

# Microgrid

**“A group of interconnected loads and distributed energy resources (DER) with clearly defined electrical boundaries that acts as a single controllable entity with respect to the grid and can connect and disconnect from the grid to enable it to operate in both grid-connected or island mode.”**

***- US. Department of Energy definition***

**Plain Language:** in many respects, microgrids are smaller versions of the traditional power grid.

**Q:** Why do we need microgrid?

- **Easy integration of local renewable energy into the grid**
- **Increased local control, reliability and security of power**



**Microgrids can help neighborhoods keep the lights on in an extreme weather situation like Hurricane Sandy.**



**Super storm Sandy Black Out in Lower Manhattan**



# Electric Vehicles (EV)

## Charging Station



In Electric Vehicles system, information exchange is required between EVs, charging stations and billing and management systems.

**Q:** what communication technology can be used for this requirement?

Power line communication can be a solution, utilizing installed power lines, providing strong security and enabling large scalability

# References

- **Department of Energy, “The Smart Grid: An Introduction”, at [https://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE\\_SG\\_Book\\_Single\\_Pages.pdf](https://energy.gov/sites/prod/files/oeprod/DocumentsandMedia/DOE_SG_Book_Single_Pages.pdf)**
- **V.Gungor, D. Sahin, T. Kocak, S. Ergut, C. Buccella, C. Cecati, and G. Hancke, "A Survey on Smart Grid Potential Applications and Communication Requirements", IEEE Transactions on Industrial Informatics, vol. 9, no.1, pp.28-42, Feb. 2013.**
- **Y. Yan, Y. Qian, H. Sharif, and D. Tipper, "A Survey on Smart Grid Communication Infrastructures: Motivations, Requirements and Challenges" IEEE Communications Surveys & Tutorials, vol.15, no.1, 2013**